(2)

Bistable Vertical Cavity Surface Emitting Lasers

Grant Number: N00014-91-J-1952

Annual Report

Office of Naval Research

Young Investigator Program

June 30, 1992

Principal Investigator:

Dennis G. Deppe

Contact: Microelectronics Research Center
The University of Texas at Austin
Engineering Sciences Building 433B
Austin, Texas 78712
Tel. (512) 471-4960
Fax. (512) 471-8575

STATUS OF WORK

This work takes both theoretical and experimental paths in the study of how optical microcavities influence light emission from semiconductors. Computer simulation is used to guide the development of physical models for spontaneous and stimulated emission under the cavity influence, with experimental demonstrations used as tests of the models and to gain further insight.

Initial experimental device results have demonstrated that bistability can be achieved in the VCSEL, but the source of the bistability has not been clearly defined as of yet in our experimental work. We have demonstrated the usefulness of our particular device design, as evidenced in our optical switching to achieve optical memory, described in Publications 1 and 6. An intriguing possibility for the source of the bistability lies in the details of an optically thin gain region and its placement in the Fabry-Perot microcavity. The bistability then might arise due to changes in the field overlap with the gain region when the device bias is increased from below lasing to above threshold. The lasing threshold behavior then changes from what is typically a second-order phase transition to a first-order transition, which exhibits hysteresis. Experimental evidence of this first-order phase transition in the lasing threshold is presented in Publication 5. We are currently working to develop more detailed computer models of the laser threshold, to theoretically study this first-order transition as well as to guide our device design.

We have also undertaken detailed studies using both computer modelling and experimental measurement to investigate the semiconductor Fabry-Perot microcavity influence on spontaneous emission, and this work has led to several submissions to technical journals for publication. Dipole localization in the microcavity is found to have a significant impact on the spectral emission as well as intensity emitted from semiconductor microcavities. The usual interpretation of resonant cavity modes as having some intrinsic dependence on photon lifetime in the cavity is found to be incorrect, and only occurs due to averaging over many dipole positions. Interesting interference effects due to the same

spontaneous photon emitted in opposite directions are found to dominate the spectral characteristics of the cavity influenced emission. We are further developing our computer models used to describe VCSELs to incorporate these cavity effects, which are not observed in more standard edge-emitting semiconductor lasers.

Our future work will continue to build on these models and to realize both test structures and practical working lasers designed to take advantage of the interesting cavity controlled emission.

PUBLICATIONS UNDER ONR SUPPORT

1. D.L. Huffaker, W.D. Lee, D.G. Deppe, C. Lei, T.J. Rogers, J.C. Campbell, and B.G. Streetman, "Optical Memory Using a Vertical-Cavity Surface-Emitting Laser", IEEE Photon. Tech. Lett. 3, 1064-1066 (December, 1991).

2. D.G. Deppe and C. Lei, "Electrodynamics and Controlled Spontaneous Emission in Microcavity Semiconductor Lasers," IEEE IEDM Tec. Dig., Dec. 8-11, 1991, Washington.

3. D.G. Deppe and C. Lei, "Spontaneous Emission and Optical Gain in a Fabry-Perot Microcavity", Appl. Phys. Lett. 60, 527-529 (3 February, 1992).

4. C. Lei and D.G. Deppe, "Optical Gain Enhancement in Fabry-Perot Microcavity Lasers", J. Appl. Phys. 71, 2530-2535 (15 March, 1992).

5. D.G. Deppe, D.L. Huffaker, T.J. Rogers, C. Lei, Z. Huang, and B.G. Streetman, "First-Order Phase Transition in a Laser Threshold", Appl. Phys. Lett. 60, (22 June, 1992), to be published.

6. D.L. Huffaker, D.G. Deppe, C. Lei, T.J. Rogers, B.G. Streetman, S.C. Smith, and R.D. Burnham, "Cascadability of an Optically Latching Vertical-Cavity Surface-Emitting Laser", Electron. Lett. 28, 734-736 (9 April, 1992).

7. D.L. Huffaker, C. Lei, D.G. Deppe, C.J. Pinzone, J.G. Neff, and R.D. Dupuis, "Controlled Spontaneous Emission in Room Temperature Semiconductor Microcavities", Appl. Phys. Lett. 60, (29 June, 1992), to be published.

8. D.L. Huffaker, Z. Huang, C. Lei, D.G. Deppe, C.J. Pinzone, J.G. Neff, and R.D. Dupuis, "Effect on Spontaneous Emission of Quantum Well Placement in a Short Vertical Cavity", Appl. Phys. Lett., to be published.

9. C. Lei, C.J. Pinzone, Z. Huang, D.L. Huffaker, D.G. Deppe, J.G. Neff, and R.D. Dupuis, "Room Temperature Spontaneous Emission in 5μm Long AlGaAs Vertical Cavities", submitted to J. Appl. Phys.

10. C. Lei, Z. Huang, D.G. Deppe, C.C. Lin, D.L. Huffaker, T.J. Rogers, C.J. Pinzone, and R.D. Dupuis, "Wave Packet Picture for Spontaneous Emission", submitted to Appl. Phys. Lett.

11. Z. Huang, C. Lei, D.G. Deppe, C.C. Lin, C.J. Pinzone, and R.D. Dupuis, "Spectral and Intensity Dependence on Dipole Localization in Fabry-Perot Cavities", submitted to Appl. Phys. Lett.

12. C. Lei, D.G. Deppe, Z. Huang, and C.C. Lin, "Emission Characteristics From Dipoles with Fixed Positions in Fabry-Perot Cavities", submitted to IEEE J. Quant. Electron.

13. D.G. Deppe, "Expression for Gain Based on Einstein Coefficients for a Short Cavity Semiconductor Laser", manuscript in preparation.

CONFERENCE PRESENTATIONS UNDER ONR SUPPORT

1. D.G. Deppe, D.L. Huffaker, C. Lei, W.D. Lee, T.J. Rogers, J.C. Campbell, and B.G. Streetman, "Bistability and Optical Switching in an AlGaAs-GaAs-InGaAs Vertical-Cavity Surface-Emitting Laser", 49th Annual Device Research Conference, June 17-19, 1991, Boulder, paper IIIA4.

2. (Invited) D.G. Deppe and C. Lei, "Electrodynamics and Controlled Spontaneous Emission in Microcavity Semiconductor Lasers," International Electron Devices Meeting, Dec. 8-11, 1991, Washington.

3. D.G. Deppe, D.L. Huffaker, C. Lei, C.J. Pinzone, J.G. Neff, and R.D. Dupuis, "Controlled Spontaneous Emission in Room Temperature Microcavities", WOCSEMAD, Feb. 17-19, 1992, San Antonio.

4. (Invited) D.G. Deppe, "Spontaneous Emission in Semiconductor Microcavities", Rank Prize Fund Minisymposium, September 21-24, 1992, Grasmere, England, to be given.